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CONTENTS

Development of Weldable High-Strength Aluminum Alloy

906C3834A Tokyo BOEI GIJUTSU in Japanese Sep 89 pp 66-72

[Article by Masakazu Hirano, Moka Laboratory, Research Division, Production Bureau, Light Alloy Rolled Copper Operation Headquarters, Kobe Steel, Ltd.: "Characteristics of Weldable Superhigh-Strength Aluminum Alloy KS7055"]

[Text] **Foreword**

As part of the progress in science and technology in recent years, the development of lightweight structures has been remarkable, as can be observed by such facts as full-scale research on the practical use of magnetically levitated train having been begun, and that following the successful development of the H-I rocket, an independent technical development program for the H-II rocket is being steadily promoted. In line with such technical innovations, the role of high-strength aluminum alloys with a high specific strength, which are represented by 2024 and 7075, has become more and more important, and higher-performance materials are being demanded. In response to this, based on the damage allowable design philosophy, for instance, material development by new concepts, such as high-strength aluminum alloys with improved toughness and stress corrosion cracking resistance (SCC resistance), Al-Li alloys, P/M (quenching powder metallurgy) alloys and composite materials, is now being carried out energetically, and the replacement of existing materials with these materials has begun.[1-4]

Incidentally, although welding is ideal for assembling lightweight structures, since the conventional high-strength aluminum alloys can hardly be melted and welded, they must be joined by bolts and rivets when assembled as structures. This could represent a major obstacle in rationalizing structures, reducing assembling cost, and, according to uses, improving airtightness, but no effective solution for this has yet been found. Weldable aluminum alloys include 2219,[5] which is actually used in rockets and aircraft, the JIS 7N01 alloy (Kobe Steel's CZ5D), which is often used in land transportation vehicles, such as railway rolling stock, 4,000 units of which have actually been manufactured, and the NSD alloy (Kobe Steel's CZ5F), which is used in special vehicles, and each of which has its own advantages. With the remarkable progress in science and technology in recent years, however, further higher-strength weldable aluminum alloys are being sought as materials for extra lightweight structures.

Kobe Steel was quick to tackle the development of weldable high-strength aluminum alloys, and has currently developed a weldable superhigh-strength alloy, KS7055, which meets the above-mentioned requirements. Since the high-strength aluminum alloys, as other metal materials, tend to cause SCC when the strength increases, one object when developing high-strength materials has been to improve the weldability and, at the same time, the SCC resistance.[6,7] The KS7055 alloy has been developed by solving these problems. This paper introduces the characteristics of this alloy by comparing them with those of conventional alloys.

1. Chemical Composition

The chemical composition of the KS7055 alloy is shown in Table 1. This is an Al-Zn-Mg system alloy with Zn and Mg as the bases, and its SCC resistance has been improved by adding very small quantities of Cu and Ag and combining the manufacturing conditions. In addition, measures have been taken to add very small quantities of Zr to improve the weldability and stabilize the structure, and Ti-B to make the cast structure uniform.

2. Mechanical Properties

2.1 Tensile Characteristics

From the KS7055 alloy, extruded material and forging, in addition to sheets, can be manufactured. The tensile characteristics of this alloy as a base metal and welding material in these products are shown in Table 2, and are compared with those of the conventional typical high-strength aluminum alloys.

Table 1. Chemical Composition of KS7055 Alloy, wt%

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Ag	Al
equal to or less than 0.30	equal to or less than 0.40	0.05-0.40	equal to or less than 0.40	1.3-2.3	equal to or less than 0.30	5.5-6.5	equal to or less than 0.15	0.05-0.20	equal to or less than 0.30	Rem.

Table 2. Tensile Characteristics of KS7055 Alloy

Alloys and temper1)	Type2)	Base metal			Welded joint3)		
		TS, kgf/mm^2	YS, kgf/mm^2	El., %	TS, kgf/mm^2	YS, kgf/mm^2	El., %
KS7055-T6	Sheet	51.9	47.0	13.6	36.8	27.5	5.8
KS7055-T6	Shape	54.8	48.0	12.5	37.4	29.6	4.2
KS7055-T6	Forging	49.3	41.1	8.5	35.4	25.0	5.9
2219-T87	Sheet	47.2	39.1	10.0	29.1	21.2	3.4

Table 2. Tensile Characteristics of KS7055 Alloy (Continued)

Alloys and temper[1)]	Type[2)]	Base metal			Welded joint[3)]		
		TS, kgf/mm^2	YS, kgf/mm^2	El., %	TS, kgf/mm^2	YS, kgf/mm^2	El., %
CZ5D-T6(7N01)[4)]	Sheet	37.0	32.2	14.1	33.0	21.2	8.4
CZ5F-T6(NDS)[4)]	Sheet	43.6	37.4	14.1	33.3	21.4	7.3
2024-T4	Sheet	48.2	34.3	14.4	—	—	—
7075-T6	Sheet	56.2	49.1	11.2	—	—	—

1) T6, T87, T4: Temper symbol

2) Sheet: Thickness 6 mm; Shape: Extruded bar 20 x 100 mm; Forging: Free forged

3) Bead on

Filler alloy: 5356 for KS7055, CZ5D, CZ5F, 2319 for 2219

4) Kobe Steel Ltd.'s alloy corresponding to JIS 7N01 or NDS alloy

As for strength as a base metal, KS7055 is next to 7075-T6, whose strength is the highest among the aluminum alloys, and is higher than 2024-T4, thereby placing it in the top class of high-strength aluminum alloys. Both in the extruded material and forging, it has high strength, although differences occur depending on the product's shape. Since the 2024 and 7075 alloys cannot be melted and welded on a practical basis, 2219 has the highest strength among conventional weldable aluminum alloys, followed by CZ5F and CZ5D, respectively. KS7055 is approximately 10 percent higher in tensile strength and about 20 percent higher in yield strength than 2219.

As for strength as a welding material, among conventional alloys, CZ5F and CZ5D are roughly the same and are the highest. These are about 10 percent higher in tensile strength and equal in yield strength as 2219. Their order is reversed from that when comparing base metals. This is because with CZ5F and CZ5D, which are Al-Zn-Mg system alloys, the welding-affected parts liquefy due to welding heat and are quenched through cooling, so after once softening they recover their strength through natural aging. The 2219, an Al-Cu system alloy, does not have this effect.[8] KS7055 causes the same age hardening as CZ5F and CZ5D. It is about 30 percent higher both in tensile strength and yield strength than 2219, and about 15 percent higher in tensile strength and 30 percent higher in yield strength than CZ5F and CZ5D.

On the other hand, it is thought that the strength of 2219 can be somewhat improved if artificial aging is applied following welding, and can be improved further to the same strength as that of KS7055 if the solution, quenching and aging are conducted after the welding.[5] However, this is seldom adopted on a practical basis because of such problems as heat treatment expenses and quench distortion.

The welded joint efficiency of the KS7055 alloy is about 70 percent. As for the riveted joint efficiency of 7075, although there are differences according to the design, an instance of about 35 percent has been reported.[9] Therefore, the joint strength can be expected to be markedly improved if the KS7055 welded joint is adopted.

2.2 Tensile Characteristics at Low Temperatures

Aluminum alloy applications at low temperatures include superconducting linear motors, rocket fuel tanks, high energy physics research equipment, etc., and full-scale studies are being promoted toward their practical use. Since the most common of the low-temperature structures are low-temperature liquefied gas containers and heat-insulating vacuum containers, a welded construction that can secure airtightness is required. Consequently, low-temperature structure materials must have base metal and weld zone characteristics that are high in strength and show no brittleness at low temperatures.

The tensile characteristics of the KS7055 alloy base metal and welding material at the liquid nitrogen temperature of 77K and liquid helium temperature of 4.2K are shown in Figure 1. Since aluminum alloys generally are not brittle and improve in mechanical properties even at low temperatures, they are suitable for use as low-temperature construction materials.[10] KS7055, too, both as a base metal and welding material, is markedly high in tensile strength and yield strength, and also becomes somewhat longer at low temperatures. The 2219 and CZ5D also have high strength at low temperatures, but likewise in the case of normal temperature, the KS7055 has superior tensile characteristics.

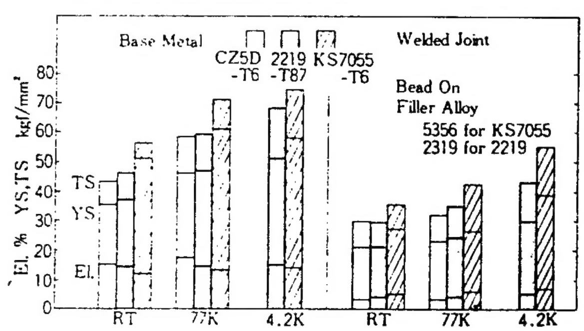


Figure 1. Tensile Characteristics of KS7055 Alloy at Low Temperatures

2.3 Toughness

The fracture toughness values of the KS7055 alloy base metal and welding material are shown in Figure 2. The fracture toughness value of the base metal is roughly equivalent to that of the 2219 alloy, and higher than that of 7075. The fracture toughness value of the weld zone is higher than that of 2219 in both welding methods. When comparing the welding methods, the toughness value is higher in the electron beam welding (EBW) than in the MIG welding.

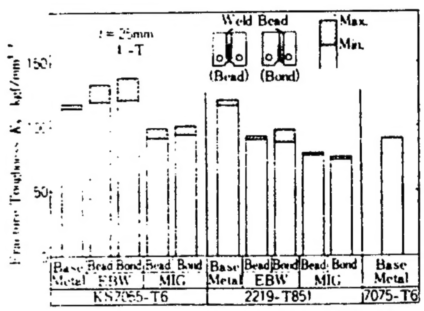


Figure 2. Fracture Toughness of KS7055 Alloy

2.4 Fatigue Strength, Fatigue Crack Propagation Characteristics

The axial tension fatigue strengths of the KS7055 alloy base metal and welding material are shown in Figure 3. Generally, the fatigue strength has a strong correlation with the tensile strength. Corresponding to its tensile strength, the fatigue strength of KS7055 is markedly higher than that of CZ5D, standing at a high value next to that of 7075. The fatigue crack propagation rate is shown in Figure 4. KS7055 tends to have a slightly higher propagation rate than 7075.

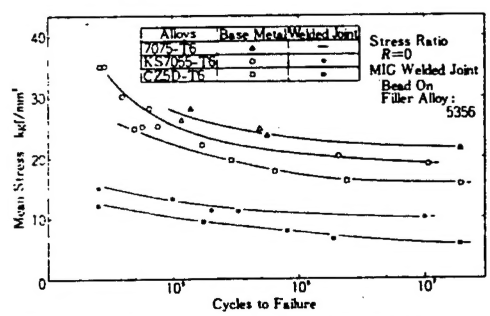


Figure 3. Fatigue Strength of KS7055 Alloy

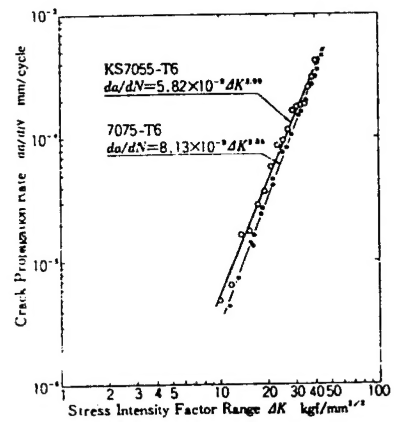


Figure 4. Fatigue Crack Propagation Rate of KS7055 Alloy

3. Weldability

The KS7055 alloy can be welded by such general methods as TIG and MIG welding, and also by melt welding, such as high-current MIG welding (HMIG) and electron beam welding, as well as by resistance welding, such as spot welding and seam welding. The filler alloy used is 5356 or 5183, which is frequently used for structures in general. The tensile strengths of welded joints of 25 mm thick sheet by various welding methods are shown in Figure 5. Electron beam welding resulted in the highest strength, followed by high-current MIG welding and MIG welding, respectively.

The KS7055 alloy's strength is, as described above, higher than that of 2219, both in base metals and welding

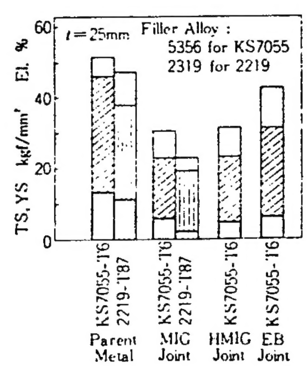


Figure 5. Tensile Characteristics of KS7055 Alloy Welded Joint

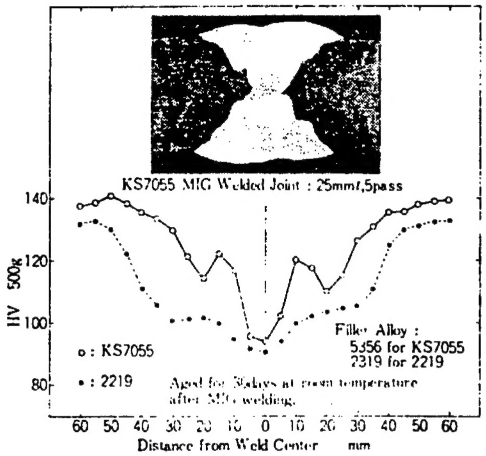


Figure 6. Hardness Distribution of KS7055 Alloy MIG Welded Joint

materials. The hardness distribution of the MIG welded joints of the two alloys are shown in Figure 6, demonstrating that the hardness of the base metal and welded joint of KS7055 is higher than that of 2219. The filler alloy for KS7055 is 5356 and, therefore, the welded metal section is markedly lower in hardness than the base metal. This suggests the possibility of the joint strength being improved by the development of high-strength filler alloys.

The weld crack of aluminum alloys is intergranular hot crack, as is the forging crack. The Al-Zn-Mg system alloys increase their strength when the quantities of Zn and Mg are increased, but they tend to cause cracking due to the widening of the solidus-liquidus space.[11] The effect of the components on the susceptibility of the KS7055 alloy to weld cracking was examined. As a result, it was proven that although having different optimum additions, the addition of Zr and Ti-B is effective for correcting weld cracking, while the addition of Mg and Cu deteriorates the weldability.[12] For KS7055, the main component and minor additional components have been determined to improve the weldability after improving the strength and SCC resistance and controlling the macrocrystal.

The results of comparing the weld crack traits of the KS7055 alloy with those of CZ5D are shown in Figure 7. KS7055 tends to cause welding cracking easier than CZ5D, but when welded at a speed of 400 mm/min, which is generally used for construction, it does not differ from CZ5D. On the other hand, in the KS7055 alloy, it is conceivable that similar to other Al-Zn-Mg system alloys, when the heat input during welding is too large, intergranular local melting will take place in the welding-heat affected section, thereby lowering the joint strength. Such being the case, there must also be management actions in the aspect of work execution, such as

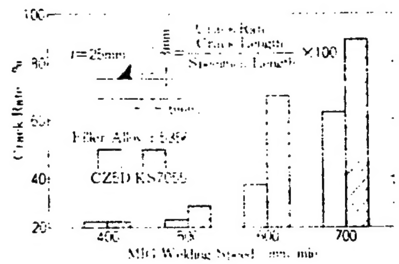


Figure 7. Weldability of KS7055 Alloy

restricting the frequency of repair welding and adopting welding conditions that prevent too much heat from being input.

4. Corrosion Resistance

The KS7055 alloy, like other high-strength aluminum alloys, is relatively poor in corrosion resistance, and it is recommended that sufficient coating be applied to it. Its corrosion consists of very slight pitting corrosion in the outdoor air, but in fresh water, sea water and humid environments, sometimes layered peeling corrosion occurs. Therefore, it is necessary to take design measures to prevent water retention, and to apply sufficient coating.

Generally, the high-strength aluminum alloys, as is the case with the other metal materials, tend to cause SCC with an increase in strength and, therefore, improving the SCC resistance has been a major problem in developing the KS7055 alloy. Since the SCC of aluminum alloys is caused in the grain boundary due to the existence of tensile stress in the corrosion atmosphere, it is greatly affected by the materials' structure. In the parallel direction (L) and the right-angle direction (LT) with regard to the rolling direction, crystal grains extend in the processing direction and, therefore, tensile stress applied to the grain boundary is small and susceptibility to cracking is low, but in the sheet thickness direction (ST) of thick sheets, the SCC resistance is relatively poor. In the actual construction, therefore, design considerations have been taken to prevent the stress from being applied in the ST direction.[13]

The SCC resistance in the ST direction of the KS7055 alloy base metal is shown in Figure 8. In this respect, KS7055-T6 is markedly higher than 7075-T6 and 2024-T4, exhibiting performance characteristics equal to those of 7075-T73, which has the highest SCC resistance among the high-strength aluminum alloys. Also, depending on the welding conditions, it is possible that SCC will occur due to residual stress in the joint end face and the toe of the weld. The results of air exposure tests conducted by preparing various types of welded joints are shown in Table 3. In all joint shapes, no cracking occurred during the 2-year test period. Such being the case, with the adoption of KS7055, reliability of the SCC resistance in the base metal ST direction and the welded joints increases, thereby making it possible to rationalize the high-performance joint design and the design execution.

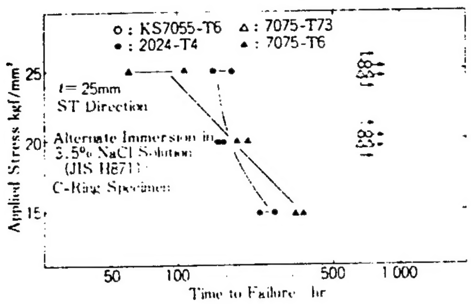
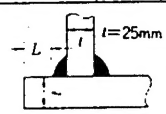


Figure 8. SCC Resistance of KS7055 Alloy in Alternate Immersion Test

Table 3. SCC Resistance of KS7055 Alloy Weld Joints in Air Exposure (2-Year) Tests

Alloys	$L = 0t$	$1/2t$	$1t$	$1\frac{1}{2}t$	$2t$
KS7055	○○	○○	○○	○○	○○
CZ5D	× ×	○○	○○	○○	○○



○ : No failure
× : Failure

Much research has been conducted on the SCC development mechanism, leading to the intergranular preferential melting theory,[13] the preferential plastic deformation theory[14] and the recently announced hydrogen embrittlement theory.[15] Photo 1 [not reproduced] shows the KS7055's electron microscopic observation results, while Photo 2 [not reproduced] is its intergranular precipitate EDS analysis results. There were few insoluble compounds, and fine and uniform precipitates were observed in the grains. In the grain boundary, precipitates emerged coarsely and continuously, and a very narrow PFZ (precipitate free zone) was observed. As the result of intergranular precipitate EDS analysis, it was observed that in addition to the main components Zn and Mg, such minor additional elements as Cu and Ag were preferentially precipitated.

The author, et al., confirming that, with Cu and Ag added, the intergranular preferential melting of the Al-Zn-Mg system alloys is alleviated and a shift to general corrosion occurs, thereby increasing the SCC resistance, have clarified that the SCC development mechanism can be explained by the intergranular preferential melting theory.[16] The current development of the KS7055 alloy with a high SCC resistance is a fruit of this research.

Conclusion

The characteristics of the weldable superhigh-strength aluminum alloy KS7055 can be summarized as follows:

(1) Exhibiting a tensile strength of 50 kgf/mm^2 or above as a base metal, this alloy has top-class strength among the high-strength aluminum alloys.

(2) It can be welded by ordinary melt welding, such as TIG and MIG welding, as well as by resistance welding, such as spot welding and seam welding.

(3) Its welded joint strength is about 30 percent higher in tensile strength and yield strength than that of the conventional weldable alloy 2219.

(4) It has a high SCC resistance, equivalent to that of 7075-T73, which has the highest SCC resistance among the high-strength aluminum alloys.

By applying this alloy, melt welding in large lightweight structures, which have thus far been constructed by joining such conventional high-strength aluminum alloys as 2024 and 7075 by rivets and bolts, becomes possible, thereby leading to a marked weight reduction, performance improvement and rationalization of design and construction. Such being the case, its uses as machine parts in land transportation vehicles, robots, etc., and as structural materials for low-temperature containers, linear motor cars, rockets, etc., in the high technology field can be expected.

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JDA Director General Issues FY90 Defense Program Directive

43062096A Tokyo BOEI GIJUTSU in Japanese Jul 89 pp 71-74

[Text] Director General Tazawa of the Japan Defense Agency on 29 May issued guidelines to the chairman of the Joint Staff Council, Chiefs of Ground, Maritime, and Air Staffs, and the chief of the Technical Research and Development Institute for the preparation of FY 1990 program. The contents are as follows.

Self-Defense Forces

The FY90 program should cover the following items, keeping in mind that it will be the final fiscal year of the current mid-year defense plan. We must consider such matters as the completion of the consolidated operational posture and the completion of balanced, high-quality frontline and rear defense capabilities. Our efforts to achieve further efficiency and compatibility in both of these phases will also be affected by the present severe financial situation.

Another factor to keep in mind is that the next mid-term defense plan beginning in FY91 is already being developed.

1. Completion/modernization of the ground-defense forces, with emphasis on more firepower and maneuverability of antitank, artillery, and antiship weapons.

2. Continued work on warships and antisubmarine aircraft to improve antisubmarine, air defense, antimine capabilities.

3. Improved air defenses with the production of interceptors, airborne early-warning aircraft, surface-to-air missiles and upgrading the F4EJ interceptor.

4. Continued efforts to improve our emergency response posture and decrease the vulnerability of our military bases by increasing the sustainability of Japanese forces through increased stockpiles of materiel such as ammunition, the transfer of part of our tank force to Hokkaido, and the completion of various rear support programs, such as improved transport capacity.

5. Improved command and control communications by completing the consolidated defense communications network, an information network, improving our electronic warfare capacity, and additional research on an over-the-horizon radar.

6. Promotion of intensive education and training programs; maintenance and improvement of expertise by conducting various exercises, including Japan-U.S. joint exercises; and preparation of various measures to prevent training accidents.

7. Further upgrading of facilities, such as barracks and quarters;improved working environment for personnel; efforts to complete facilities required to keep bases operational.

8. Recruitment of personnel required for the maintenance/operation of the defense forces and efforts to improve organizational efficiency.

9. Continued study/improvement of personnel benefits such as pensions; improvement of the recruitment program and support operation; completion of reserve personnel system.

10. Research on ways the defense program should incorporate future military technology in addition to conducting various defense-related research.

Technical Research and Development Institute (TRDI)

The 1990 program for TRDI should focus on the following items aiming at enforcement of the mid-term defense plan's final fiscal year. It should promote conditions conducive to technical research and development, paying particular attention to progress in Japan-U.S. R&D cooperation. At the same time, our efforts to increase efficiency and compatibility of technical R&D should keep in mind the present severe financial situation.

Further, adequate consideration should be given to the fact that the next mid-term defense plan beginning in FY91 is under examination at present.

1. Technical Development

The R&D of carefully selected new items will be conducted; in addition several programs already started will continue, including the next- generation fighter, a short-range SAM (improved version), and antisubmarine mini-torpedoes.

Further, the joint Japan-U.S. development of the next-generation fighter will be conducted efficiently and as planned with close cooperation by incorporating the advanced technologies of both countries.

2. Technical Research

(1) Efforts to improve the technology for aircraft, guided weapons, electronic equipment, especially taking the technical levels of other countries into consideration. In this process, future development of systems must be considered in the elemental research area as well.

(2) Complete the basic technology in firearms, fighting vehicles, warships, and other equipment.

(3) Promote technical research to use high technology in military equipment.

3. General Items of Development and Research

(1) Promote technical R&D on software for use in command communication, information networks, and electronic warfare.

(2) Improve equipment already on hand and encourage technical R&D for their modernization.

(3) Direct efforts to promote interoperability among the Self-Defense Forces and between Japan and the United States, and at the same time conduct the technical R&D aimed at reducing costs through massproduction.

(4) Study the benefits of R&D cooperation with the United States.

4. Other

(1) Oversee implementation of defense-related technology transfer agreements, between Japan and the United States as well as develop technical exchange between the two countries.

(2) Complete a testing and evaluation system for high-performance firearms and ammunition.

Trends in Energy R&D Outlays Reviewed

90CF0360A Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 11 Jan 90 p 4

[Text] **Trend of Energy Research Outlays: From the General Affairs Agency Investigation**

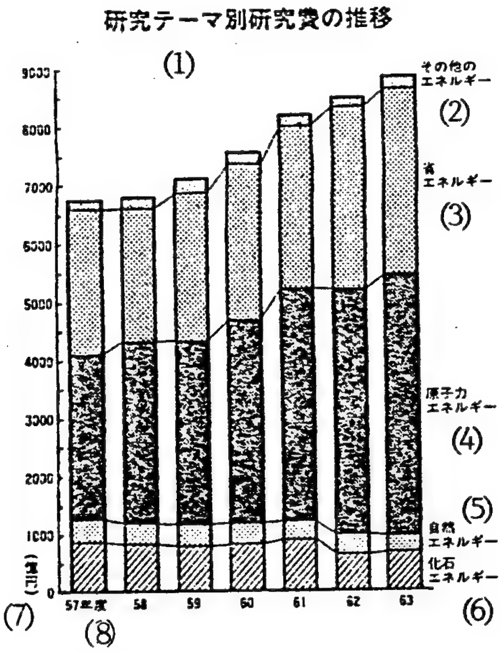
Nuclear Energy Occupies 50 Percent of a Total Amount of ¥889.3 Billion

As reported in an earlier edition, the Statistics Bureau of the General Affairs Agency recently put together a report on the trend of Japan's energy research outlays. According to that report, the total amount spent on energy research in FY88 was ¥889.3 billion (an increase of 4.2 percent over the previous year). Of this total, 50.6 percent was spent on nuclear energy research. Below is a summary of the findings.

Total Amount of Research Expenses

The total amount of energy research expenses for FY88 was ¥889.3 billion. Compared to FY87 (¥853.3 billion), this was an increase of ¥36 billion, or 4.2 percent.

If we take a look at the changes of recent years regarding comparisons with earlier years, we can see that from 1975 to 1980, the rate of increase was from 24 to 39 percent, which continued to grow well above the rate of increase for science and technology outlays overall. However, since 1982 (6.5 percent), the rate of increase has fallen to a single digit rate, and with the exception of 1986, the rate of increase was below the growth of science and technology research outlays overall every year. As a result, although energy research outlays have increased greatly to where they are 3.2 times the amount 10 years ago in 1978, the increase over 1983, five years ago, is only 1.3 times.



Key:—1. Changes in research outlays by research subject—2. Other energy—3. Energy conservation—4. Nuclear energy—5. Natural energy—6. Fossile energy—7. (One hundred million yen)—8. FY1982 [57+25=1982]

Incidentally, the percentage that energy research outlays hold in the total amount of science and technology research expenditures (¥10.6276 trillion) is 8.4 percent, and has shrunk a shade since 1987, when it was 8.7 percent.

Table 1. Research Outlays By Research Subject (Unit: ¥100 million)

Research Subject	FY83	FY88	Comparison with Last Year (%)	Percent of Whole
Overall Total	6,814	8,893	4.2	-
Fossile Energy Research	848	690	4.2	100.0
Oil Energy Research	475	355	11.1	51.5
Natural Gas Energy Research	29	43	11.2	6.2
Coal Energy Research	327	260	-4.7	37.6
Other Fossile Energy Research	17	33	2.3	4.7
Natural Energy Research	361	287	-14.6	100.0
Geothermal Energy Research	71	44	-24.2	15.4
Solar Energy Research	191	143	-11.7	49.7
Marine Energy Research	16	9	-20.2	3.3
Wind Power Energy Research	10	11	9.1	3.8
Biomass Research	66	71	-10.9	24.9
Other Natural Energy Research	6	8	-40.5	2.9
Nuclear Energy Research	3,145	4,498	6.8	100.0
Nuclear Generator Research	1,073	1,728	6.4	38.4

Table 1. Research Outlays By Research Subject (Unit: ¥ 100 million) (Continued)

Research Subject	FY83	FY88	Comparison with Last Year (%)	Percent of Whole
Nuclear Reactor Multipurpose Use Research	72	168	18.4	3.7
Nuclear Fuel Cycle Research	625	1,331	8.4	29.6
Nuclear Fusion Research	759	435	1.8	9.7
Other Nuclear Energy Research	223	363	6.9	8.1
Nuclear-powered Vessel Research	74	22	-1.3	0.5
Radiation Use Research	219	248	11.3	5.5
Radiation Safety Research	101	204	-2.2	4.5
Energy Conservation Research	2,269	3,185	1.8	100.0
Industrial Fields Research	489	404	4.4	12.7
Popular Fields Research	169	246	4.5	7.7
Transportation Field Research	1,342	2,109	-1.8	66.2
Electricity Conversion and Electricity Storage Research	223	286	12.7	9.0
Hydrogen Energy Research	32	68	17.4	2.1
Other Energy Conservation Research	13	72	52.3	2.3
Other Energy Research	191	232	20.7	-

Research Outlays by Research Entity

When we look at FY88's energy research outlays by research entity, we find that research organizations spent ¥547.4 billion, companies spent ¥306.2 billion, and universities spent ¥35.7 billion.

When we make comparisons with the previous year, we find that in contrast to the companies which increased their expenses by 6.0 percent and the research organizations which increased theirs by 3.7 percent, the universities declined by 2.2 percent.

Incidentally, if we look at the percentage each occupies in the total amount of energy research outlays, we find that research organizations control 61.6 percent, or over 60 percent of the total. Following them, the companies control 34.4 percent, and the universities control 4.0 percent.

Research Outlays by Expenditure Source

With regard to FY88 energy research outlays by expenditure source, the private sector spent ¥514.6 billion (57.9 percent of the total research outlay), national government and local public groups spent ¥374.7 billion (42.1 percent of the total research outlay), and the private sector, therefore, holds a bit less than 60 percent. Comparing this to the previous year, we find that in contrast to the firm growth trend of 6.0 percent displayed by the private sector, the national government and local public groups are only sluggish, with a growth rate of 1.9 percent.

When we look at the shift of recent years in the makeup of individual disbursement sources for research outlays, we find that the share held by the private sector grew rapidly from 1975-1980, and expanded from 39.7 percent in 1978 to 57.0 percent in FY82. Since FY83, the percentage has repeatedly risen and fallen, but it has been fairly level, and was 57.9 percent in FY88.

Research Outlays by Research Subject

When we look at FY88 energy research outlays by research subject, we find that nuclear energy research expenses, at ¥449.8 billion (50.6 percent of the total amount of research outlays) occupies over 50 percent of the outlays. Next comes energy conservation research outlays at ¥318.5 billion (or 35.8 percent). These two subjects occupy 86.4 percent of the total amount of research expenses. Following them are fossile energy research outlays at ¥69 billion (7.8 percent), natural energy research outlays at ¥28.7 billion (3.2 percent), and other energy research outlays at ¥23.2 billion (2.6 percent).

When the main research subjects are compared to a year earlier, we find that nuclear energy research outlays displayed a firm tone of growth with an increase of 6.8 percent, whereas energy conservation research outlays demonstrated slow growth at 1.8 percent.

Incidentally, compared with FY83, five years ago, the research outlays by research subject are as follows. Nuclear energy research outlays and energy conservation research outlays increased at 1.43 times and 1.4 times, respectively. In contrast, fossile research outlays and natural energy research outlays declined 0.81 times and 0.79 times each.

Changes of Research Outlays by Research Entity

Section	Fiscal Year	Total Amount	Companies	Research Organizations	Universities
Research outlays (¥100 million)	78	2,780	1,124	1,436	220
	83	6,814	2,827	3,630	358
	84	7,120	2,968	3,835	317
	85	7,591	2,917	4,348	326
	86	8,235	3,014	4,878	342
	87	8,533	2,889	5,278	365
	88	8,893	3,062	5,474	357
Previous year comparison (percentage)	78	24.3	19.9	32.7	1.1
	83	0.6	-6.2	6.6	1.0
	84	4.5	5.0	5.7	-11.5
	85	6.6	-1.7	13.4	2.9
	86	8.5	3.3	12.2	5.1
	87	3.6	-4.2	8.2	6.7
	88	4.2	6.0	3.7	-2.2
Percentage of whole	78	100.0	40.4	51.7	7.9
	83	100.0	41.5	53.3	5.2
	84	100.0	41.7	53.9	4.4
	85	100.0	38.4	57.3	4.3
	86	100.0	36.6	59.2	4.2
	87	100.0	33.9	61.9	4.3
	88	100.0	34.4	61.6	4.0
Percentage occupied in science and technology research outlays by research entity	78	6.9	4.9	23.8	1.9
	83	9.5	6.2	37.4	2.2
	87	8.7	4.4	38.1	1.9
	88	8.4	4.2	39.3	1.8

Fuel Cycle More Than Doubles in Five Years

Itemization of Research Outlays by Research Subject

If we conduct a detailed itemization of research outlays by research subjects, we find that in fossile energy research outlays (totalling ¥69.1 billion), ¥35.5 billion went to petroleum energy research outlays (or 51.5 percent of the fossile energy research outlays). Next came coal energy research outlays at ¥26 billion (or 37.6 percent of the total). These two subjects hold about 90 percent of all fossile energy research outlays.

When we compare the research outlays for these two subjects with five years ago, FY83, we find that the petroleum energy research outlay has declined to 0.75 times that of 1983, and the coal energy research outlay has declined to 0.79 times that of 1983.

In the area of natural energy research expenses (¥28.7 billion), solar energy research outlays total ¥14.3 billion (49.7 percent of the natural energy research outlay) for the most amount. Next comes biomass research expenses of ¥7.1 billion (24.9 percent), and geothermal energy research expenses of ¥4.4 billion (15.5 percent). These three subjects make up 90 percent of the natural energy research expense.

When we compare this to FY83, five years ago, although biomass has increased 1.1 times, solar energy research outlays have declined 0.75 times, and geothermal energy research expenses have declined to 0.62 times.

As for nuclear energy research outlays (¥449.8 billion), nuclear power generation research outlays are ¥172.8 billion (38.4 percent of the nuclear energy research outlays), followed by nuclear fuel cycle research outlays of ¥133.1 billion (29.6 percent), nuclear fusion research outlays of ¥43.5 billion (9.7 percent), research outlays for the use of radiation of ¥24.8 billion (5.5 percent), radiation safety research expenses of ¥204 billion (4.5 percent), and nuclear reactor multipurpose use research

outlays of ¥16.8 billion (3.7 percent). The three top subjects make up more than three-fourths of all nuclear energy research expenses.

If we compare this to FY83, five years ago, we find that nuclear reactor multipurpose use research outlays have increased 2.33 times, nuclear fuel cycle research expenses 2.13 times, and radiation safety research expenses 2.03 times. Not only have the above three more than doubled, but nuclear power generation research outlays have increased 1.61 times. All these areas have increased greatly. On the other hand, radiation use research expenses have stagnated at 1.13 times five years ago, and nuclear fusion research outlays have declined to 0.57 times what they were in FY83.

As for energy conservation research outlays (¥318.5 billion), transportation field research expenses occupy about two-thirds of the category (¥210.9 billion, or 66.2 percent of energy conservation research outlays). After that comes ¥40.4 billion for industrial fields research outlays (12.7 percent), electricity conversion and electricity storage research outlays at ¥28.6 billion (9.0 percent), and popular fields research expenses at ¥24.6 billion (7.7 percent).

When we compare this with five years ago, the transportation field research expenses have increased 1.57 times, the popular fields research outlays 1.46 times, and the electricity conversion and electricity storage research outlays 1.28 times. In contrast, industrial fields research outlays have declined to 0.83 times 1983.

If we look at the percentage of research outlays each research subject occupies in each research entity, we find that for the companies, energy conservation research outlays take up over half at 51.1 percent, followed by nuclear energy research outlays at 23.9 percent, and fossile energy research outlays at 15.3 percent. In research organizations, nuclear energy research outlays occupy over 60 percent at 64.7 percent, and then energy conservation research outlays at 28.4 percent. These two subjects occupy 93.2 percent of all research organization outlays. In the universities, nuclear energy research expenses occupy 62.2 percent for the most, followed by energy conservation research outlays at 17.9 percent, and natural energy research expenses at 13.6 percent.

Number of Persons Regularly Conducting Research

The number of persons regularly conducting energy research on 1 April 1990 was 19,001 persons. Compared with five years ago, that is a slight decline at 0.98 times the earlier figure.

By research entity, 9.479 researchers work in companies (49.9 percent of the total number of researchers), 6,265 researchers work for research organizations (33.0 percent), and 3,257 researchers work in universities (17.1 percent).

When we compare this to five years ago, we find that while the research organizations increased 1.25 times, the companies declined to 0.86 times and the universities to 0.96 times the number of five years ago.

When we look at energy researchers by energy subject, 8,230 work on energy conservation, and 6,714 work on nuclear energy research. These two subjects make up 78.6 percent of the total. One thousand seven hundred sixty researchers engage in fossile [energy] research, 1,609 in natural energy research, and 688 in other energy research.

NEC 16M EPROM Cell Technology

90CF0345A Tokyo NIKKEI MICRODEVICES in Japanese Jan 90 pp 101-107

[Article by Takeshi Okazawa, Yoshiaki Hisamune, Noriaki Kodama, and Kenji Saito, VLSI Development Center, NEC]

[Text] **16M EPROM Cell Technology**

The smallest cell area is achieved by 0.9 μm gate, maintaining the writing voltage—trench isolation and self-alignment technology, ONO film being employed.

This makes the same specifications used in up to 4M ROMs applicable also to 16M devices such as the writing voltage of 12.5V, etc.

The cell size that Nippon Denki (NEC) has trial manufactured is 3.6 μm^2, the smallest, but the gate length of the cell transistor is 0.9 μm which is not greatly shortened and contributing to this success. Employing new technologies, such as stress-free shallow trench of burying BPSG for cell separation and self-aligning contact generously, the selection of the minimum of 0.6 μm dimension is achieved. However, the reduction of coupling capacitance in the control gate due to non-existing birds' beaks is compensated by an ONO film (oxide-nitride-oxide film) of equivalent thickness and the capacitance between the control gate and the floating gate is secured. The use of 0.6 μm gates is expected to make 2.25 μm^2 possible. (Journal Editor)

EPROM memory cells having a fine 16M-bit class structure but with the gate 0.9 μm long, the 4M-type transistor dimension are trial manufactured and their operation confirmed. The cell size is 2.0 x 1.8 μm^2 (3.6 μm^2), shrinking the 4M cell by 40 percent (Figure 1).

The memory cell transistor size of 0.9 μm x 1.4 μm (gate length x width) is only about 75 percent in linear dimension, 61 percent by area, of the 4M device, 1.15 μm x 1.8 μm, developed earlier by NEC.

Despite this, the reason for being able to reduce the memory cell area by 40 percent is the decrease in other than the transistor, such as the separation between the elements and the drain contact boundaries. For these parts, 0.6 μm width is used.

Limitation of Simple Scaling

The reduction in cell size is accomplished by scaling up to the 4M EPROM but the design of the 16M devices can

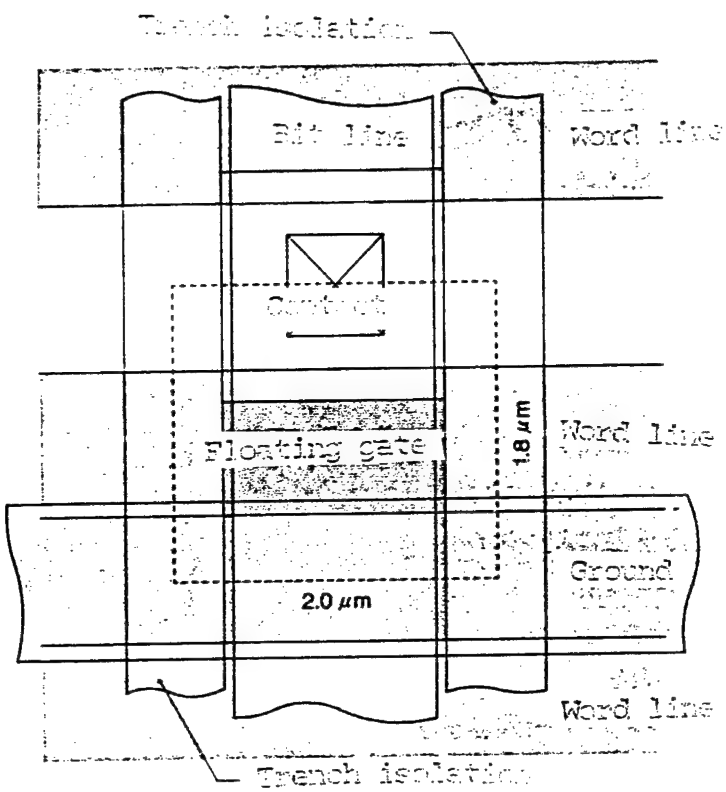


Figure 1. 16M EPROM memory cell layout

The cell size is 2.0 x 1.8 μm (3.6 μm^2), reduced by 40 percent compared to the 4M device. The design rule is 0.6 μm. The gate length and the gate width of the cell transistor are 0.9 μm and 1.4 μm, respectively.

no longer be achieved by the scaling alone. New technologies are necessary not only in the shrinking of the memory cell transistor itself but also in the isolation of the elements and contact fabrication.

The following techniques have been developed for applications in future EPROMs, EEPROMs and possibly flash-type cells:

(1) Element separation,

(2) Insulating film between polycrystalline Si,

(3) Self-aligned drain contact.

One needs first to ascertain the material capable of withstanding the voltage impressed between the adjacent elements. In the memory-write method of channel hot electron injection, the condition for maximizing the gate current is the gate voltage nearly equal to the drain voltage. Assuming the same thickness of both the upper and lower oxide layers enclosing the floating gate, the control gate voltage must be about twice that of the drain voltage when the coupling capacitance is taken into account—approximately 14V is impressed on the gate.

For isolating elements in 16M and later devices, the traditional LOCOS method is inadequate to render the voltage withstanding capability (Figure 2). The improved LOCOS method which reduces the bird's beak shows some improved performance but its limitation is obvious. The limiting channel widths of the narrow channel effect in the LOCOS and the improved LOCOS methods are 1.0 µm and 0.8 µm, respectively.

The trench isolation technique, therefore, is selected. The breakdown voltage is over 25V, which is quite high. The factor determining the isolation width is the limitation imposed by lithography. The trend isolation (Figure 3) has also an advantage of the floating gate being fabricated self-aligned with the element isolation region. Heretofore, a margin of 0.1 to 0.2 µm has been set aside for mask matching but it is no longer needed, contributing to further shrinkage of the cell.

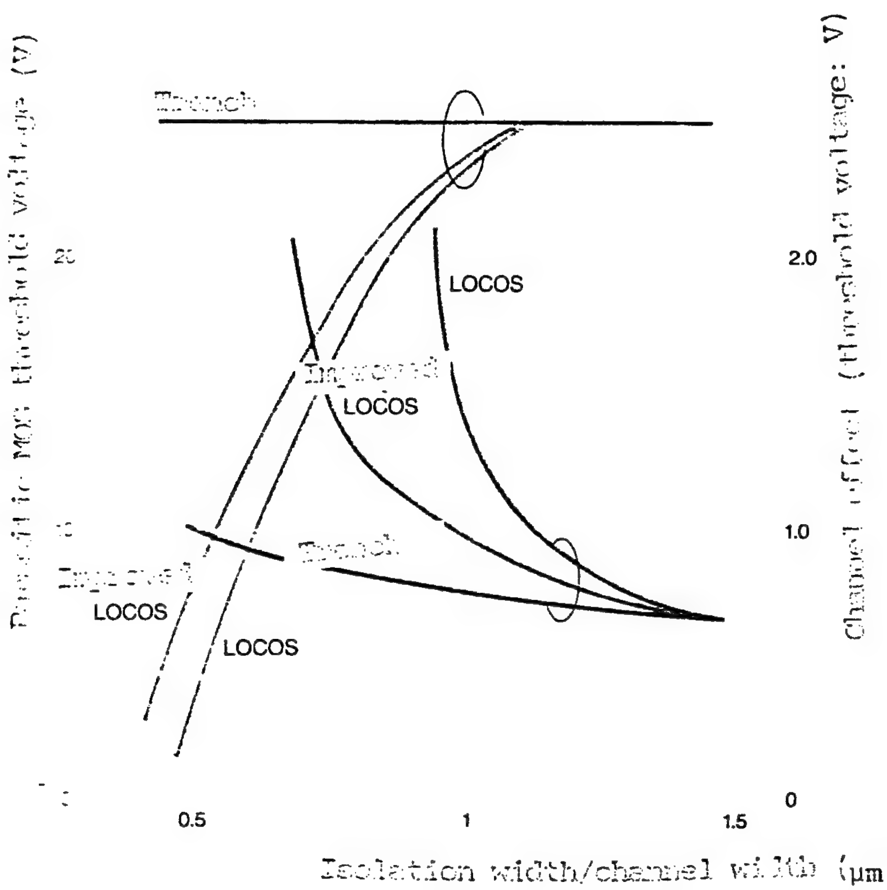


Figure 2. When trench isolation is used, the puncture resistant voltage is not degraded even at 0.6 µm separation

The channel width of 1.0 to 0.8 µm is the limit of the narrow channel effect using the normal LOCOS or the improved LOCOS which reduces bird's beak.

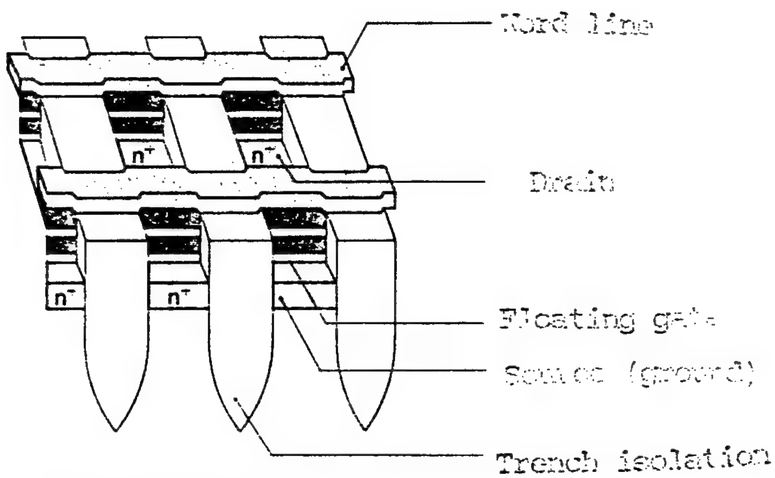


Figure 3. Schematic representation EPROM cell employing trench separation

Selection of ONO Film Securing High Breakdown Voltage

However, the techniques so far considered would degrade the capacitive coupling ratio which determines the floating gate voltage. In a LOCOS isolation, the part consumed by the bird's beak lowers the capacitance due to the first oxide film between the substrate and the floating gate, thereby substantially raising the coupling ratio.

In order to prevent degradation of the writing characteristics by a lower capacitive coupling ratio, the gate insulating film needs to be thinner. By employing the ONO (oxide-nitride-oxide) structure for the second gate oxide film between the floating gate and the control gate, a high breakdown voltage of insulation is achieved. An oxide film equivalent of 20 nm is rather thin. The first gate oxide film is 20 nm.

The bit line contact peripheries are also re-evaluated. The contact size of 0.6 μm is accepted, and the use of the W selective CVD process, after the formation of silicide pads on the source/drain, enables the 0.2 μm contact-gate spacing. As a result, the worrisome substrate erosion is avoided and a low resistance value of 25 ohms per piece is achieved. In the case of 4M device, the figure is about 30 ohms per piece which is of 1-μm square dimension.

Because a current in the order of mA flows through the cell during the write process, an increase in contact resistance substantially reduces the voltage impressed on the memory cell and the write time is slowed down.

V_{PP} Need Not Be Lowered

Must the write voltage, V_{pp}, for 16M class devices be scaled down? The current 4M devices are of the 12.5 V type since the 256K devices; and if this high write voltage is to be maintained when the gate becomes submicron size, the loading to the transistor is considerable due to a lowered breakdown voltage of the drain brought about by the gate oxide film and the floating gate potential.

On the other hand with a high V_{pp}, it is possible to keep a large differential between the voltage levels impressed on the cell at the write-time and the read-time. Accordingly, accidental memory write-over while a memory read is being performed, the so-called soft error is less likely to occur.

It is desirable to lower the V_{pp} from 12.5 V in the 16M class cell if one follows the scaling factor. It would not be meaningful unless the voltage is lowered all the way to 5 V. At an intermediate value of 7 to 8 V, for example, the same traditional technique has to be used for making the device withstand breakdown, thus there is very little merit to be realized. On the other hand, if the V_{pp} is kept at 5 V, the gate oxide film thickness must be reduced and the channel of the memory transistor must be shortened in order to keep the write-time short—a considerable amount of re-evaluation is necessary. In addition to the aforementioned soft-write problem, there is also the problem of data maintenance when the lower voltage is to be adopted. The conclusion is that a lower voltage is not necessarily required.

As the trench process itself has been in use in the capacitance part of 1M DRAMs, a considerable amount of technological information concerning the morphology and burying has been accumulated. However, the materials being buried internally are fundamentally different for capacitor formation and device isolation. For fabrication of a capacitive element an electrode needs to be fashioned within the trench, thus a conductive material such as polycrystalline Si must be buried. For isolation of devices, the purpose is to insulate one element from another, thus it is desirable to buy an insulating material.

Filling the Trench With BPSG

The trench may be filled with polycrystalline Si but the surface after burying must be insulated—oxidation under high temperatures can cause stress. The reason why the trench isolation process did not completely succeed in a CVD oxide film system heretofore is due mainly to the stress between the material being buried and the Si substrate.

However, BPSG can reduce this stress considerably. According to a report on bipolar devices, this stress is hardly a problem with BPSG. The reason is likely that BPSG film itself is under very little stress and the reflow temperature is low. Accordingly, there is hardly any junction leakage due to the trench. The same film is used in this experiment.

Furthermore, because the thermal treatment is carried out at a relatively low temperature of 900°C, there is very little B separation requiring no channel stopper. A slightly higher substrate concentration will suffice.

Shallow 1.2 to 1.5 μm Trench

In order to reduce further the effect of stress from the trench on the Si substrate, the trench is made shallow—a deeper trench requires a higher reflow temperature. In addition, an increased volume of the filler material in the trench increases the stress. For a deep trench, unevenness develops in the surface layer of reflow BPSG between the trench area and non-trench area. This makes the control of ending etching difficult for back etching. This unevenness can be prevented somewhat by making the BPSG film thicker, but the processing time then becomes longer. Experiments show that a good separation can be obtained with the trench depth of 1.2 to 1.5 μm.

In the trench forming process (Figure 4), the trench is fabricated in the diffusion zone isolated by ordinate LOCOS. It is feared that when BPSG is buried inside the trench, P and B of BPSG diffuse outward by heating during the gate oxide film formation and degradation of the film is likely to take place. In order to avoid this from happening, the first and the second insulator films are to be completed before the trench formation.

The difficult part of trench etching is to give a slightly inverted taper (more recessing toward bottom) to the four-layer film of the first gate oxide/the floating gate/the second gate insulator/the control gate. If the four layers are formed with a cleanly graduated taper, the buried BPSG forms a correspondingly opposing taper and the floating gate on the source/drain and polycrystalline Si of the control gate on the walls of the protruded part of the trench will be positioned more easily when the word line is fabricated later.

Polycrystalline Si in the control gate becomes the etching stopper when the BPSG is back-etched. The word line is formed by preparing a WSI_x film on the polycrystalline Si of the stopper in a memory cell. As the floating gate in

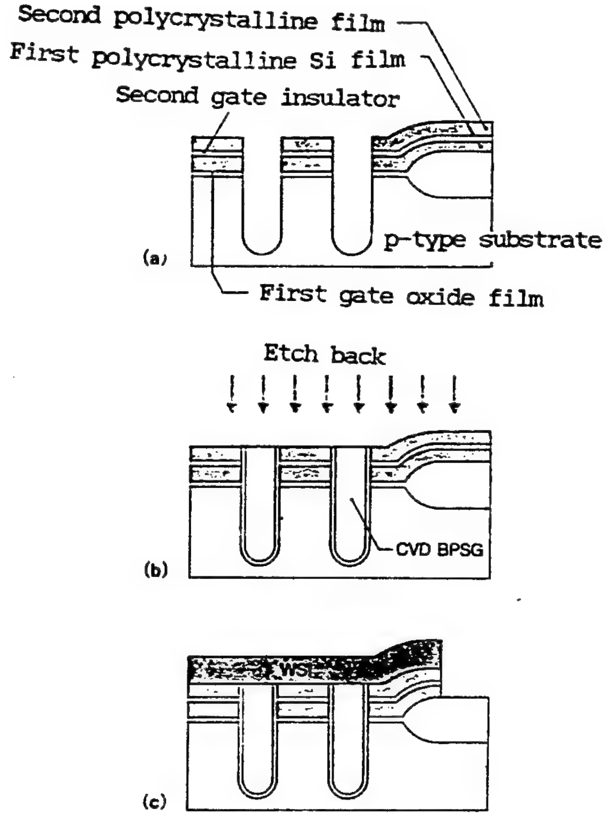


Figure 4. Trench isolation fabrication process

Two layers of polycrystalline Si are constructed then trench areas are etched. (a) LOCOS isolation and a 4-layer film of the first gate oxide layer/the floating gate/the second gate insulator (ONO layer)/the control gate are constructed, then etched successively. (b) A thin oxide film is grown inside the trench then BPSG is deposited by CVD. The BPSG is then annealed and its surface is smoothed then etched back. Polysilicon of the control gate acts as a stopper for etch back. (c) The final step is to deposit WSI_x over the polycrystalline silicon to form the word line.

the surrounding transistors must be removed, the polycrystalline Si and the ONO film in the nearby cells are removed by using a mask. The nearby transistor assumes a polysilicon gate structure including the silicide form developed on the first sheet of polysilicon.

Thin ONO Film, Oxide Equivalent of 20 nm

In order to raise the floating gate potential in the floating gate-type EPROMs, it is necessary to keep the capacitance of the second gate oxide film large and raise the potential of the floating gate close to that of the control gate. Namely, the second gate oxide film is constructed thin to gain a large capacitance.

In the past, the polycrystalline Si oxide layer of the second gate oxide film has been formed by oxidation under temperatures higher than 1100°C to be able to withstand puncture and to exhibit excellent characteristics of low DC leakage current. This is because when oxidized at low temperatures, the oxide film reflects the orientation properties of Si crystallites and its leakage characteristics are extremely poor. As oxidation takes place on polycrystalline Si at high temperatures, preparation of very thin film is very difficult. The thickness cannot be controlled easily and the leakage current characteristics degrade greatly.

The 4M device can use a sufficiently thick film in the order of 30 nm and there is no special problem, but this method of preparing thinner films has a limit at about 25 nm.

Therefore, the ONO structure which maintains good puncture proofing and leakage-current characteristics as well as high capacitance indicates promise. In order to obtain an equivalent 20 nm thickness calculated as an oxide film, a 12 nm thermally oxidized film and a 10 nm nitride film must be formed over polycrystalline Si then anneal the nitride film at 900°C under an oxidizing atmosphere. Compared with a thermally oxidized film of the same 20 nm thickness, the DC leakage current characteristics are definitely improved (Figure 5). The insulation puncture withstanding voltage also is high.

The unchanging properties of the ONO film under ultraviolet ray radiation necessary in use as an EPROM are confirmed. After scores of repeated writing and erasure (ultraviolet radiation), the variation in the threshold value before and after writing is well within the satisfactory limits.

Self-Alignment Feasibility With a Margin of 0.3 μm

A process of forming the gate through self-alignment is developed in order to reduce resistance of the drain contact which connects the bit line. First contact openings are made to the drain and the source (ground side) by a self-alignment technique and the WSI_x pad is fashioned to extend toward the gate. At this time, a CVD film thicker than the first interlayer film is deposited on the gate, so as to keep the silicide and the gate from shorting each other.

The second interlayer film is then developed to envelop the silicide pad and the gate and the drain contact opening is made on the drain silicide pad. As the drain silicide pad extends over the gate, even if a mask misalignment occurs with the contact opening and the gate, there is no shorted gate as long as it does not miss the silicide pad. The source side just requires a common ground line and its wiring connection can be performed in the same layer level as the silicide pad.

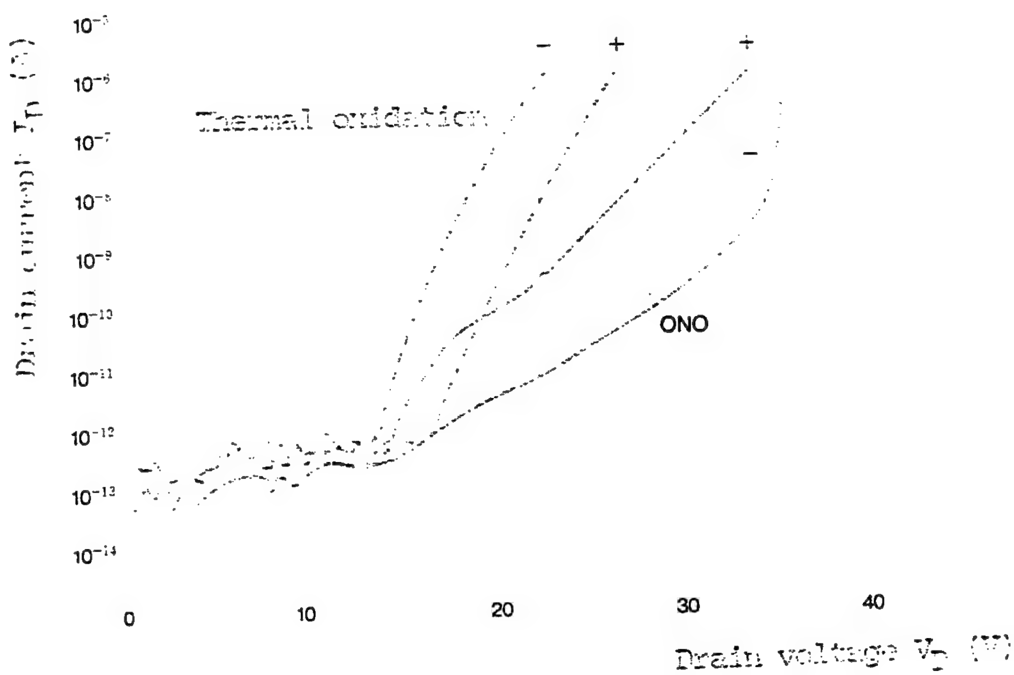


Figure 5. Low leakage current in the ONO film

The film thickness is equivalent 20 nm. The comparison is made to the oxide film of the same thickness. The + and - markings indicate the polarity of the impressed voltage to the control gate. Leakage is higher in the thermal oxide film when a negative voltage is applied to the control gate. Namely, electron injection from the electrode easy, but the ONO film makes electron injection through the floating gate easy.

The gate length of 0.9 μm is long compared to the lithography restriction of 0.6 μm providing a margin of 0.3 μm making the process possible. The minimum separation between the drain silicide pad and the silicide ground line is made to 0.6 μm positioned over the gate, allowing a margin of 0.3 μm. On this cell, the 0.3 μm overlap is partitioned into 0.2 μm on the drain pad side and 0.1 μm on the source side wiring. The drain contact is a small 0.6 μm square as the practical W-selective technology is expected to be available shortly.

With the past method of burying polycrystalline Si in the contact hole, the resistance of a 0.6 μm contact is more than 100 ohms and varies greatly so it cannot be utilized. The selective W CVD burying technique provides about 25 ohms to a 0.6 μm contact which is a satisfactory level. The W formed over the silicide pad holds the junction leakage of the n-diffusion layer immediately below. A full-scale reliability test, however, has not been conducted.

Large ON Current, so Width Can Be Small

The memory cell of the trial-manufactured 16M device is fabricated within a p well on the surface of a 12 to 15 ohm x cm p-type (100) substrate.

The ON current at read-time in the trench cell is considerably larger than that in the LOCOS isolated cell (Figure 6). Comparing the small capacitive coupling ratio (about 0.5) of the cell by trench process to that of LOCOS (about 0.7), a large ON current is proof of a broader effective channel width in the trench cell than in the LOCOS.

The question as to what level the ON current is required cannot be answered readily as it depends on the circuits which surround the device. However, as the 4M cells are fabricated through LOCOS isolation with W = 1.8 μm and L = 1.15 μm and if a similar scale of the 4M cell is maintained, it is clear that the cell size of 1.2 μm will be adequate (Figure 6).

The write speed is fast enough for a 16M class (Figure 7). The threshold value before writing is about 1.0 V and it takes about 10 μs to gain a 5 V shift. But when compared to the same cell size transistor fabricated with LOCOS isolation, this performance is rather poor. The reason is that the capacitive coupling ratio is lower in the trench separated cell. Despite this, a fast write time of 10 μs seems to be accomplished through improved electronic charge injection efficiency by thin first and second gate insulator films which make the vertical electrical potential stronger.

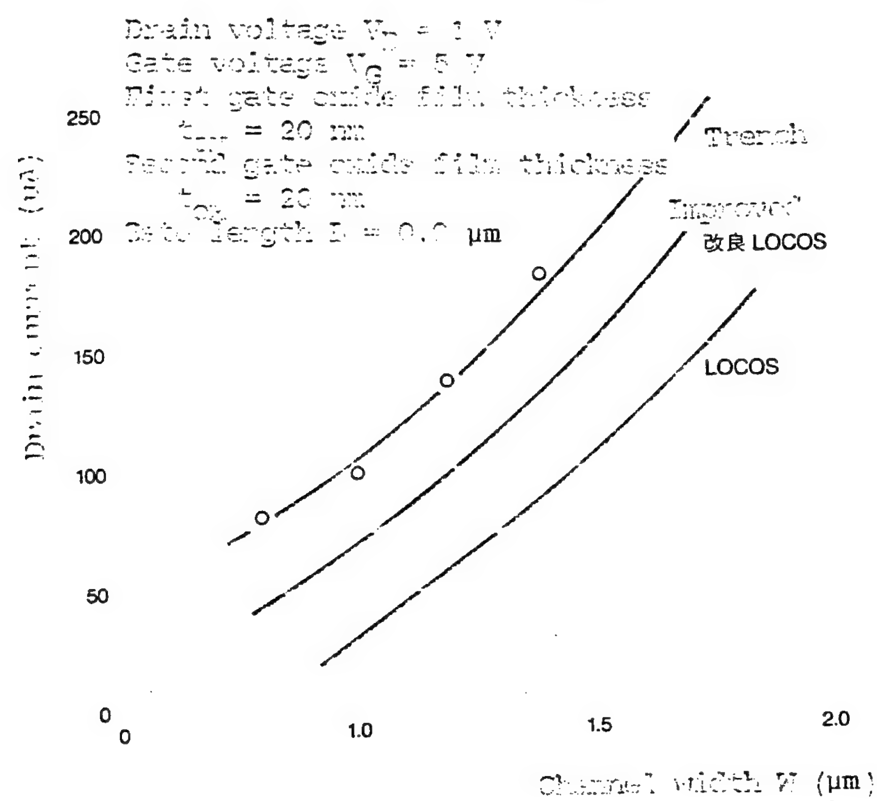


Figure 6. Large transistor current can be realized with the trench isolation

This is the ON current at read-time. The channel width of the trench cell is considered to be effectively larger than that of the LOCOS cell. A 1.2 μm gate is sufficient to obtain the same level of current of the 4M device with 1.8 μm gate.

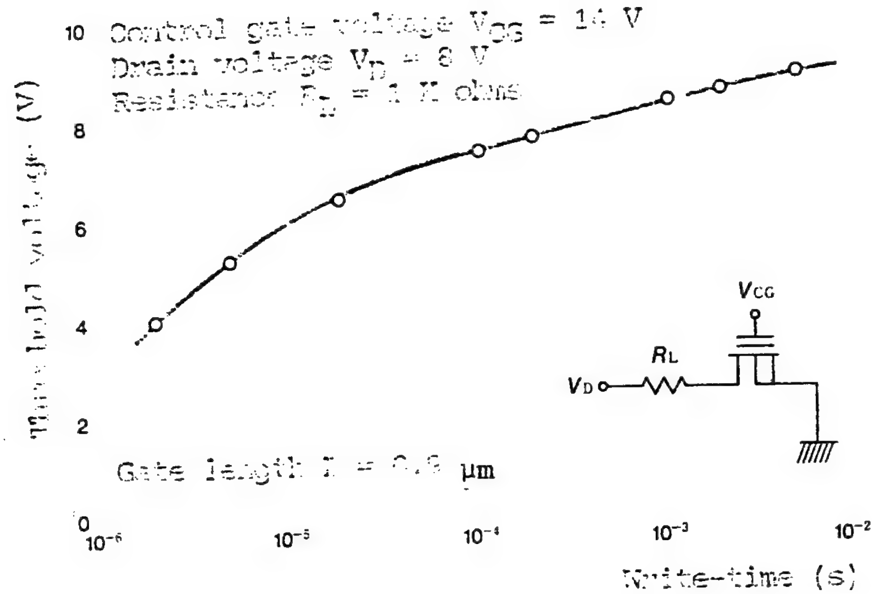


Figure 7. A 5 V shift can be carried out in 10 μs

The same bias voltage is applied as done to the actual cell. Even when V_{pp} is 12.5 V, the actual voltage impressed on the control gate is raised to 14 V. The threshold voltage before writing is about 1 V. Writing is performed through hot-electron channel injection. The write-speed is an adequate value for a 16M class device, but poor by the amount poorer in the capacitive coupling ratio compared to the transistor of the same size fabricated through the LOCOS isolation.

Measurement of the write disturbance to the unselected cell which has already been written to indicates that the threshold value does not change even after 100 s—when a disturbance comes to a cell which had already been written to (the threshold value shifts toward positive direction at off condition), the threshold value of the cell normally should go down.

0.6 μm Gate To Make 64M Class Possible

It is certainly agreed that the ONO has the best promise to be interlayer insulator between polycrystalline islands in future floating-gate-type EPROMs including the flash type. How thin can the ONO be prepared? It is also related to lowering V_{pp} voltage, but the main keypoint is how thin the basic bottom O layer, that is, an oxide film over the polycrystalline Si, can be prepared. The leakage characteristics of the foundation layer determine the properties of the entire ONO film. Indeed, when the foundation oxide film is made thin, the leakage characteristics under high electrical potential deteriorates significantly. However, there is a possibility for improving the foundation film by using CVD, etc.

There are a number of problems to be solved in the selective W CVD technology. There are some initial reliability test data available but long-term data are still rare.

Further shrinking of memory cells is possible. If the cell transistor is made to become 0.6 μm X 0.9 μm (gate length X gate width), the cell of 1.5 μm X 1.5 μm (2.25 μm^2) become possible even the separation and contact peripheries are held at the same size as the current trial device. With this size, it is possible to aim for 32M and 64M class devices. The V_{pp} may have to be lowered to about 5 V in that case. Even using the thin 12 to 15-nm polycrystalline Si oxide films by scaling and employing the ONO structure, it is probably very difficult, as generally believed, to keep the V_{pp} voltage at 12.5 V because of a possible puncture in the gate insulator film and the drain.

Government Standards for Power Plant Accidents Described

90CF0195A Tokyo GENSHIRYOKU KOGYO in Japanese No 35, Sep 89 pp 2-3

[Text] **Standards for Evaluating Nuclear Power Plant Accidents and Mishaps**

Government standards for evaluating accidents have been set, which is a move "from safety that could not be seen to safety that can be seen." In addition to the Ministry of International Trade and Industry [MITI] announcing "Accident and Mishap Evaluation Standards" for nuclear power plants, the Science and Technology Agency [STA] decided on the "accident and mishap impact stages (rank of degree of impact)" for nuclear power facilities such as atomic reactors used for research, reprocessing facilities, and nuclear fuel processing facilities. By these means, it was decided to attach a rank to every nuclear power facility accident or mishap in Japan.

Both MITI and STA divided their evaluation scales into nine stages for the general public. Their objective in doing this was to cause the standards to spread like those for earthquakes. The first country in the world to attach ranks by stages to nuclear power plant accidents and mishaps in a manner similar to the seismic scale of earthquakes was France. Japan is the second. All Japanese nuclear power facilities operating on 25 July of this year will have these standards applied to them.

Accidents in nuclear power facilities enliven the front page of newspapers on a daily basis. It is only natural for the average person to think that with this type of accident occurring, how dare it be said that these facilities are safe.

Ever since the Chernobyl accident in the Soviet Union, every nuclear power plant accident in Japan began to be announced practically one after another. Consequently, a strong impression developed since that time that these accidents had increased dramatically. The average person could no longer determine the gravity of an accident and the situation became one that invited overanxiousness.

When we refer to accidents and mishaps in nuclear facilities, we are referring to a wide variety from temporary cessation of operations to confirm safety to the release of radioactivity into the environment.

Because of this, the authorities are welcoming these standards.

MITI's evaluation standards were devised after the establishment of the Nuclear Power Plant Accident and Mishap Evaluation Standards Research Group, which is headed by Tokyo University Professor Toshiyuki Kondo, at the end of last year.

The evaluation standards consist of (1) dividing the standard measurement into nine stages from levels zero through eight, with the degree of risk increasing at each stage, (2) evaluating three different viewpoints in the criteria, which are "the amount of radioactive matter released outside the nuclear power plant or facility" (Criterion 1), "the amount of radiation to which power plant employees are exposed beyond the amount projected" (Criterion 2), "the condition of the nuclear power facility" (Criterion 3), and (3) a public standard which compares the three criteria and determines the rank based on the criteria with the highest risk.

Of these three criteria, the amount of radioactive matter released outside the facility consists of nine stages from Level 0, which is "nothing is released beyond what is plainly natural radioactivity," to Level 8, which is "the predicted amount of exposure of the region inspected near the nuclear power plant is more than 100 millisieverts."

Similarly, the amount of radiation to which employees are exposed consists of six stages from Level 0, which is "less than 5 millisieverts," to Level 5, which is "more than 200 millisieverts."

The current state of nuclear reactor facilities is divided into five stages from Level 0, which is "event unrelated to safety" to Level 4, which is "event with a grave impact on safety."

According to this evaluation standard, the Soviet Union's Chernobyl accident achieved the highest level of 8 because a considerable portion of the reactor's inventory was released into the atmosphere and the average amount of radioactivity to which a resident of the surrounding 30 kilometers environs was exposed was 0.12 sieverts. In the Three Mile Island accident, which occurred in the United States 10 years ago, the highest amount of radiation to which the general population was exposed was about one millisievert, or about a Level 5.

The damage to the recirculation pump which occurred in Tokyo Electric Power's Fukushima Number Two Nuclear Power Plant was a Level 3. The leakage of radioactive material from Nippon Atomic Power's Tonga 1 Power Plant, which occurred in April 1981 was Level 0 in terms of Criterion 1 and Criterion 2. According to the radioactivity evaluation from the estimated radioactivity of the radioactive waste fluids leaked into the general sewer system, the amount of radiation in a whole body over a 50-year period would be .003 millirems. However, the final determination was Level 2 because there was leakage outside the jurisdiction of the atomic power plant facility.

According to MITI, there were 390 cases of mishaps and trouble reported by nuclear power plants across the nation during the seven years starting in 1981.

If the new ranking system were applied to this, 12 percent of these cases were Level 2 and included automatic shutdowns of reactors because the water level within the reactor had risen abnormally and manual shutdowns because of leaking from the steam generating

vessels. Thirty-seven percent were Level 1, such as reactors ceasing to operate because of an erroneous signal that the water level was low. The rest were all Level 0 and unrelated to the safety of the nuclear reactor.

France has already implemented a 7-stage ranking. If the Japanese cases were applied to this system, over half would be Level 1 or less.

Consequently, MITI, by classifying the degree of risk very finely, has established a ranking that can separate even the most minor troubles into specific levels.

For example, it is a system wherein even in accidents where no radiation is leaked, the ranking level will be high if the reactor ceases operation automatically because it will meet the Criterion Three, namely, that it is related to safety because of the "condition of the nuclear power plant facility."

Committee Chairman Kondo has said, "Accurately conveying the significance of an unusual event or mishap to a nuclear power facility is not easy. I do not think that the provision of decisions based on this sort of standard will be able to alter conditions immediately. The accumulation of a great deal of dialog is needed for that, perhaps. However, I think that this sort of evaluation standard, at least, is able to provide a common arena for this dialog." As represented by these remarks, this experiment can be considered one of trial and error and a step towards a greater dialog.

Of course, there are those who voice misgivings. The following is a representative comment: "As far as the goal of knowing the size of an accident, this will probably serve as a point of reference, but using this standard by itself may cause close sight to be lost of the cause of great accidents."

"In the case of earthquakes, mere vibrations are not considered to be 'unfelt earthquakes' because they are daily common phenomena by which the earth 'lives.' However, although Level 0 of the nuclear power plant is rated for phenomenon unrelated to safety, this rating does not change if unusual phenomenon occurred. Perhaps it should be raised to Level 1 in those cases in the sense of prodding the attention of the site employees."

"The greatest doubt is whether by publicly announcing this standard, the impression will be strengthened that a nuclear power plant accident carries the same risk as an earthquake."

"Even though the numbers are the same, the situation is different from that of an earthquake. Everyone feels the impact of an earthquake. The impact of a nuclear accident is only understood by authorities. Moreover, the frequency of light earthquakes gradually releases energy and subsides. A nuclear accident is different. After numerous occurrences [releases of radiation] as at the time of Three Mile Island, the accident becomes a major one. The idea that if the number of releases of radiation is few, then the accident is light is dangerous."

The task of the new system will be how plant operation should be carried out in the future since the impact on society will be the major problem. "The story behind one accident contains hundreds and thousands of unusual occurrences." We must not foster an attitude that ignores trivial mishaps and does not see in them the seeds of large accidents and troubles.

If there is an issue to spread to future [plant] operations, it is the demand for a flexible posture of prompt "review."

Cooperation With Developing Countries Reported

90CF0195B Tokyo GENSHIRYOKU KOGYO in Japanese No 35, Sep 89 pp 40-41

[Text] **Current Status of International Cooperation with Developing Countries in the Atomic Energy Field**

Japan's international research cooperation in the atomic energy field is proceeding actively on a bilateral basis, multilateral basis, and through such organizations as the International Atomic Energy Agency (IAEA), the Organization of Economic Cooperation and Development's Nuclear Energy Agency (OECD/NEA), etc. The various branches of cooperation are safety research, exchange of regulations information, fast breeder reactors, and nuclear fusion.

In particular, even though there is a gap among China, South Korea, and the ASEAN countries in the degree of their progress in recent years, they all have a great desire to progress on the development and use of atomic energy. Their expectations of Japan, which is the most advanced atomic energy nation in Asia, are high in terms of cooperation in the field of the peaceful uses of nuclear energy, such as radiation and RI [radioactive isotope] use, research reactor use, and nuclear power plants.

Government Agencies

(1) Nuclear energy research exchange system: This has been implemented by STA, which has accepted researchers from, and sent researchers to, nine Asian countries.

(2) Technical cooperation in the nuclear power plant field: This has been implemented by MITI, which is sending experts to various countries and accepting their trainees.

(3) Technical cooperation by the Japan International Cooperation Agency [JICA]: JICA is accepting trainees (for individual or group courses), sending experts, and providing equipment and materials.

(4) Cooperation through IAEA: By this means, the acceptance of trainees, the sending of experts, and the conducting of joint research is being implemented with an emphasis on the uses of isotopes and radiation through the Asian Region Atomic Energy Cooperation Program (RCA).

Subjects being covered in these programs are the industrial uses of radiation, the medical and biological uses of radiation, and radiation protection. There have also been requests related to research reactors, and this is being studied.

Besides this, invitations to visit Japan are extended to key figures in the atomic energy field of developing countries every year by the Atomic Energy Committee and STA, and management trainee seminars for administrators are conducted every year by STA. Furthermore, since 1988, a database of information concerning experts in the atomic energy field who could be sent overseas in cooperative programs has been implemented along with a registry and facility through which atomic energy experts could be sent overseas.

Moreover, the Japan Atomic Energy Research Institute [JAERI], the Power Reactor and Nuclear Fuel Development Corporation [PNDC], and others are carrying out cooperation base on research cooperation arrangements with atomic energy agencies of developing countries.

Universities

The public universities, in particular, are accepting foreign students for degree purposes or for training. The number of foreign students in 1988 was 62. Moreover, the Nuclear Engineering Department of Tokyo University established an international course (for five students) in order to widen the acceptance of foreign students this year.

Private Sector

Beginning with the Japan Atomic Energy Industry Congress, the Overseas Electric Power Investigative Association and the Power Plant Facility Technology Inspection Association have signed protocols, dispatched experts, and received trainees.

Moreover, electricity enterprises have carried out mutual visits on the basis of "sister company" relationships with electric power companies in South Korea and Taiwan.

The current status of cooperation, such as protocols and arrangements with the related agencies of various countries is shown in Table 1.

Table 1. Protocols and Arrangements with the Related Agencies of Various Countries

Name of Japanese agency	Partner country	Name of agency	Year of agreement	Contents
Japan Analysis Center	Taiwan	Radiation Detection Operations Group	26 May 1987	Technical exchange of environmental radioactivity analysis
	South Korea	Atomic Energy Safety Center of the Energy Research Institute	3 March 1989	Protocol on technical cooperation in the environmental radioactivity analysis and estimation field
Chugoku Electric Power	Taiwan	Electric Power Company	1966	Sister companies agreement
	Taiwan	Electric Power Company	1967	Protocol on mutual inspection
	Taiwan	Electric Power Company	1982	Protocol on technical exchange of executives
Kyushu Electric Power	South Korea	Electric Power Company	1969	Technical training exchange agreement
	South Korea	Electric Power Company	1977	Protocol on technical trainees
	South Korea	Electric Power Company	1984	Cooperation protocol on electricity enterprises
Industrial Development Research Institute	Indonesia	Technology Evaluation and Applications Agency (BPPT)	1986	Protocol on acceptance of technology-related foreign students
Japan Atomic Energy Cultural Promotion Foundation	South Korea	Atomic Energy Industry Conference	15 April 1987	Protocol on atomic energy cultural exchange cooperation
Atomic Energy Industry Conference	South Korea	Atomic Energy Industry Conference	1973	Protocol on future cooperation
	China	Nuclear Industry Ministry	1981	Protocol on cooperation in the peaceful uses of nuclear energy field
	Czechoslovakia	Atomic Energy Committee	1986	Protocol on cooperation in the science and technology field of the peaceful uses of nuclear energy
	Taiwan	China Nuclear Power Society	20 February 1989	Protocol on raising of the safety of nuclear power facilities
Kansai Atomic Power Conference	Taiwan	Nuclear Power Association	1984	Agreement on the establishment of a Japan-China [Taiwan] Atomic Energy Liaison Group
Power Plant Facility Technology Investigative Society	South Korea	Atomic Energy Safety Center of the Energy Research Institute	1985	Based on a request for cooperation from the deputy director of the Energy Research Institute

Table 1. Protocols and Arrangements with the Related Agencies of Various Countries (Continued)

Name of Japanese agency	Partner country	Name of agency	Year of agreement	Contents
Nuclear Safety Bureau of STA	South Korea	Atomic Energy Safety Cooperation Office of the Science and Technology Department	1985	Exchange of letters for cooperation in the field of emergency policy for the environs of a nuclear power plant
JAERI	Indonesia	Atomic Energy Agency (BATAN)	1 May 1984	Arrangement on research and development cooperation on radiation processing treatment
	Indonesia	Atomic Energy Agency (BATAN)	17 March 1988	Arrangement for cooperation in the use and safety of research reactors, the production and use of radioactive isotopes, radiation protection, and radioactive waste product management field
	South Korea	Energy Research Institute	1985	Bilateral arrangement on implem entation of a cooperative research program in atomic energy safety and its related fields
	Malaysia	Atomic Energy Agency (UTN)	9 December 1987	Implementation arrangement on research cooperation in the radiation processing field
PNDC	Niger	Mineral Resources Development Corporation	1981	Niger [sekire] Project Basic Agreement
	China	Uranium Mining Geological Bureau of the Nuclear Industry Ministry	1984	Agreement on an investigation of widening the uranium resources region
Institute of Physical and Chemical Research	China	Modern Physics Laboratory of Academica Sinica	20 June 1988	Protocol on the implementation of mutual sending of researchers, joint experiments, and seminars in the heavy ion field
	Indonesia	Atomic Energy Agency (BATAN)	1980	Research and cooperation arrangement on pest eradication
	Indonesia	Atomic Energy Agency (BATAN)	1984	Arrangement on developmental research cooperation into pharmaceuticals and agricultural poison chemicals such as poisons for unknown insects, fish, and shellfish
Central Electric Power Research Institute	Taiwan	Electric Power Company	8 September 1988	Research cooperation agreement on electricity enterprises including atomic energy
	South Korea	Electric Power Company	14 March 1989	Research cooperation agreement on electricity enterprises including atomic energy
Overseas Electric Power Investigation Association	South Korea	Electric Power Company	1979	Agreement on technical cooperation
	China	Nuclear Industry Ministry	21 April 1987	Protocol on technical cooperation in nuclear power generation
Kyoto University Nuclear Reactor Experimental Laboratory	Argentina	Barcelo Graduate School of Cuyo University	7 October 1988	Protocol on scientific cooperation and exchanges
Tohoku University Engineering Department	China	Zhejiang University Engineering Department	24 July 1985	Agreement on technical exchange of science and technology
	South Korea	[Chonbuk] University Engineering University	26 February 1985	Exchange of personnel and technical data for education and research in the engineering field

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